

SYNTHETIC AND NATURAL NAKHLA PYROXENES: PARENT MELT COMPOSITION AND REE PARTITION COEFFICIENTS. G. McKay (SN4, NASA-JSC, Houston, TX, 77058) L. Le, and J. Wagstaff (Lockheed ESCO, 2400 NASA Rd. 1, Houston, TX 77058)

Summary. Nakhla is one of the SNC meteorites, generally believed to be of Martian origin. It is composed mainly of cumulus augite [e.g., 1], in which primary igneous zoning is apparently preserved [2], and which thus serves as a recorder of the composition of Nakhla's parent melt and the conditions under which it crystallized. Knowledge of the composition and petrogenesis of this parent melt may help unravel Nakhla's relationship to the other SNCs, and provide clues to Martian petrogenesis in general. This abstract reports new results of an ongoing study [3, 4, 5] in which we are (1) comparing the major and minor element compositions of synthetic pyroxenes crystallized from various proposed parent melt compositions with those in Nakhla pyroxene to constrain the composition of the parent melt, and (2) measuring minor and trace element partition coefficients, particularly those of the REE, in order to obtain the most applicable D values with which to invert the natural pyroxene compositions to obtain the trace element composition of the parent melt. Results suggest that recent estimates of Nakhla's parent melt composition [6, 7] are too aluminous, and that mafic or ultramafic melts are more likely candidates. REE partition coefficients for such melts are 2-4x lower than those for "normal" basaltic melts.

Experiments. We have studied (1) pyroxene/melt equilibria and (2) partitioning of REE and Sr for four synthetic compositions resembling several proposed Nakhla parent melt compositions, as shown in Fig. 1. These compositions ranged from "ultramafic", with $\text{Al}_2\text{O}_3 < 3 \text{ wt\%}$ and $\text{FeO} + \text{MgO} > 35 \text{ wt\%}$, to "basaltic", with $\text{Al}_2\text{O}_3 \sim 8\%$ and $\text{FeO} + \text{MgO} \sim 23\%$. Charges were doped with 0.5-1% REE oxide or SrCO_3 , placed on Pt wire loops, fused at 1300°C overnight in gas mixing (CO/CO_2) furnaces, quenched, and then placed back in the furnaces at temperatures just below the pyroxene liquidus ($\sim 1200^\circ\text{C}$ for NL, $\sim 1215^\circ\text{C}$ for NT, $\sim 1225^\circ\text{C}$ for NJ and $\sim 1150^\circ\text{C}$ for NJ2) at $f_{\text{O}_2} = \text{QFM}$ and quenched after ~ 4 days. Quenched charges contained glass, a small amount of Ca-rich pyroxene, and spinel. Crystals and melts were analyzed for major and trace elements with the electron microprobe. We have previously reported results for NL, NT, and NJ, and here we report new results for NJ2.

Results: Pyroxene compositions. Fig. 2 compares quadrilateral components of pyroxenes from our experiments with those of pyroxene cores in Nakhla. Each balloon contains virtually all analyzed pyroxenes from several experiments with the indicated starting composition. Except for NT pyroxenes (which have a range of Wo contents), the synthetic pyroxenes are nearly homogeneous in quadrilateral components. All are slightly less Fe-rich than Nakhla cores, suggesting the Nakhla parent melt had slightly higher f_m values than any of our starting compositions. The NT pyroxenes are significantly lower in Wo than Nakhla cores, while NL and NJ2 pyroxenes are slightly higher. Wo content of synthetic pyroxenes appears to roughly anti-correlate with proximity to the low-Ca liquidus phase volume in Fig. 1, and thus to the degree of "over-" or "under-saturation" in low-Ca pyroxene. Our experiments appear to bracket the degree of low-Ca pyroxene "undersaturation" of the Nakhla parent melt.

A major issue for Nakhla petrogenesis is whether the parent melt was ultramafic or basaltic. As pointed out by Longhi and Pan [8], pyroxene equilibria can help constrain this issue. Fig. 3 compares

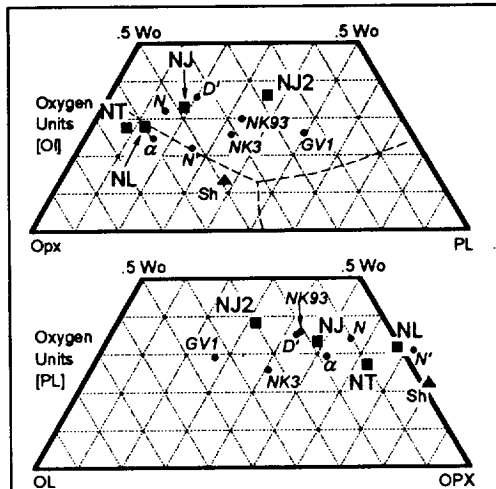


Fig. 1. Projections from Ol (top) and Pl (bottom) showing our quenched melt compositions (NT, NL, NJ, NJ2), the Shergotty analog melt for which we previously measured DREE (Sh), and proposed nakhlite parent melt compositions N [8], α [9], NK3 and GV1 [6], NK93 and N' [7], and D' [1, 7]. Olivine-saturated multiple saturation curves are after Longhi and Pan [8]. The starting compositions for our experiments are based on Longhi & Pan's composition N (our NL), an abandoned Tennessee composition α (our NT), a variation of Treiman's now-abandoned composition D' (our NJ), and Treiman's recent composition NK3 (our NJ2).

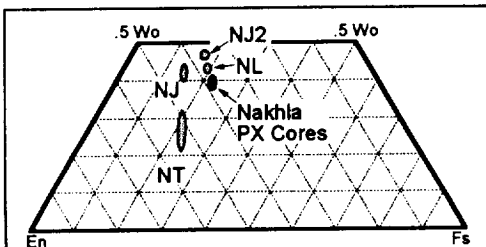


Fig. 2. Comparison of major element compositions of synthetic pyroxenes with those of natural pyroxene cores in Nakhla.

NAKHLA PYROXENES: PARENT MELT AND PARTITION COEFFICIENTS

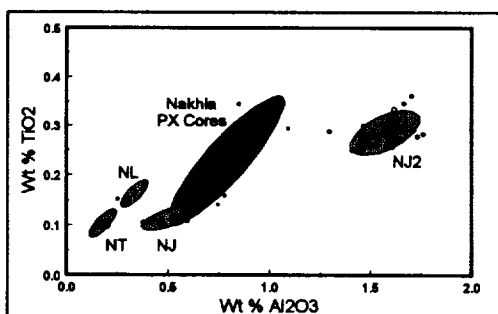
McKay, G. *et al.*

Fig. 3. TiO_2 and Al_2O_3 contents of synthetic pyroxenes and natural pyroxene cores in Nakhla. Each dot represents an individual pyroxene analysis. For synthetic pyroxenes, analyses were taken on several spots per grain, several grains per charge, and several experiments per starting composition. Nakhla analyses were taken on several spots per grain, on many grains.

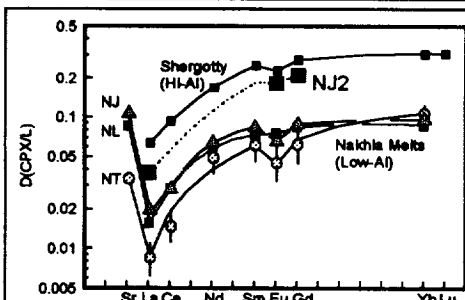


Fig. 4. REE and Sr pyroxene/liquid partition coefficients. Shergotty values are extrapolated from values observed for less calcic pyroxenes [10]. Values for low-Al Nakhla melts are from [3, 4]. Values for NJ2, our "basaltic" Nakhla parent melt composition, are new data.

one of the proposed high-Al melts. It is not clear whether the difference in Al content is responsible for most of the difference in D values, or whether the large difference in temperature (1150°C vs. 1200°–1230°C) is the most important factor. In either case, it is clear that use of the "wrong" set of partition coefficients for inverting the Nakhla pyroxenes to obtain the melt REE content can lead to errors of up to ~500% in estimated REE concentrations. Thus, in order to compute the trace element composition of the Nakhla parent melt with any confidence, it is important to gain a better understanding its major element composition, especially its Al content and liquidus temperature.

Sector zoning in pyroxene: A messy complication. Although Fig. 3 suggests that our experiments provide good constraints on the Al content of the Nakhla parent melt, this interpretation may be oversimplified. We previously reported a strongly bimodal distribution of Al concentrations in Nakhla pyroxene cores [5]. Our early attempts at elemental mapping indicated that this distribution is not simply a result of normal core-to-rim primary zoning, but is the result of a more complex process such as sector zoning. We have not had the opportunity to collect additional mapping data on Nakhla sections, so do not yet completely understand the cause or nature of this Al zoning, or how it relates to our synthetic pyroxenes. However, a bimodal distribution of Al contents for NJ2 pyroxenes is clearly evident in Fig. 3, with one cluster of analyses around 1.5% Al_2O_3 and one around 1.7%. BSE photos and elemental mapping indicate that sector zoning is responsible for this zoning. Additional work will be required to understand the implications of this zoning for attempts to constrain the composition of the Nakhla parent melt.

References: [1] Treiman (1986) GCA 50, 1061. [2] Harvey and McSweeney (1992) GCA 56, 1655. [3] McKay *et al.* (1992) LPS XXIII, 643. [4] McKay *et al.* (1993) LPS XXIV, 966. [5] McKay *et al.* (1993) Meteoritics 28, 395. [6] Harvey and McSweeney (1992) EPSL 111, 467. [7] Treiman (1993) GCA 57, 4753. [8] Longhi and Pan (1989) PLPSC 19, 451. [9] Harvey and McSweeney (1991) Met. Soc. Abs., 85. [10] McKay *et al.* (1986) GCA 50, 927.

* $D_{\text{Px/L}}$ values observed for Yb and Lu for Wo_{25} pyroxenes in [10] were nearly as high as the extrapolated Wo_{40} values in Fig. 4, but the D_{La} and D_{Ce} were closer to the values in Fig. 4 for the low-Al Nakhla melts.

Al_2O_3 and TiO_2 contents of our synthetic pyroxenes with those of Nakhla pyroxene cores. Al contents of NT and NL pyroxenes are significantly lower than those for Nakhla, while the most Al-rich pyroxenes from our NJ experiments overlap the Nakhla field. NJ2 pyroxenes contain *considerably* more Al than the Nakhla core pyroxenes. Thus, taken at face value, the data in Fig. 3 suggest that the Al content of the Nakhla parent melt is somewhat higher than that of our low-Al starting compositions (NL, NT, and NJ), but considerably lower than that of our high-Al composition (NJ2).

REE and SR partition coefficients. Fig. 4 shows partition coefficient patterns for each of our Nakhla starting compositions, together with a pattern derived from our experiments on a Shergotty parent melt [10]. We computed the latter pattern by extrapolating the partition coefficients observed for Wo_{12-25} pyroxenes in our Shergotty experiments to Wo_{40} (the composition of the natural pyroxene cores in Nakhla), using equations for variation of D_{REE} with pyroxene Wo content from [10].*

Compared with the "ultramafic" Nakhla compositions NJ, NL, and NT, the melt in the Shergotty experiments was rich in Al, and we had speculated [3, 4] that it was this difference in Al content that was largely responsible for the 3–8 fold difference in partition coefficient values. However, the Shergotty values were extrapolated, and the melts in that study differed in many compositional details from proposed Nakhla parent melts. Thus, without actual measurements for high-Al Nakhla parent melt compositions, we could not be sure that the low values might not hold even for high-Al melts.

Our new results for the NJ2 composition confirm our earlier speculation that D values from the low-Al melts are too low to be applicable if the Nakhla pyroxenes crystallized from